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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

WASHINGTON, D.C. 20546

MAR 7 1975

REPLY TO
ATTN OF: GP

TO: KSI/Scientific & Technical Information Division
Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General
Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.	: <u>3,864,239</u>
Government or Corporate Employee	: <u>Caltech Pasadena, CA</u>
Supplementary Corporate Source (if applicable)	: <u>JPL</u>
NASA Patent Case No.	: <u>NPO-13,345-1</u>

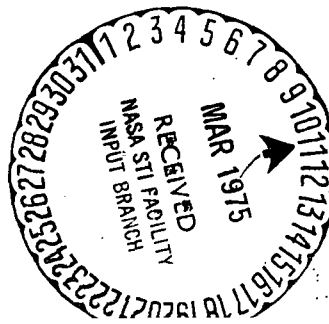
NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES ☒ NO ☐

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

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Enclosure



N75-19684

Unclas
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(NASA-Case-NPO-13345-1) MULTITARGET
SEQUENTIAL SPUTTERING APPARATUS Patent
(NASA) - 8 P
CSCL 13H

**[54] MULTITARGET SEQUENTIAL
SPUTTERING APPARATUS**

[76] **Inventors:** **James C. Fletcher**, Administrator of the National Aeronautics and Space Administration with respect to an invention of; **Rindge Shima**, 1344 Franklin St., Santa Monica, Calif. 90404

[22] Filed: Apr. 22, 1974

[21] Appl. No.: 462,705

[52] U.S. Cl. 204/298, 204/192

[51] Int. Cl..... C23c 15/00

[58] **Field of Search**..... 204/192, 298

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Grifka; John R. Manning

[57] **ABSTRACT**

A sputtering apparatus includes a single cathode on

which a plurality of targets of different materials are supported, with a rotatable anode, supporting a substrate and/or substrates, spaced apart from the cathode in a chamber containing an inert gas at a selected pressure. A potential difference is applied between the cathode and anode to produce a plasma for each target, which is sputtered by accelerated ions within the plasma. Apertured plates and shields are positioned between the targets and the anode to effectively separate the plasmas into separate columns. The sputtered material from each target having access to the substrate/substrates only through that target's column. The shields are biasable by a voltage gradient to simultaneously and equally control the current in each plasma. Each column has a separate bias ring associated therewith, which is biasable to a separate voltage to individually control the plasma in its associated column. Also included are movable shutters. The various parts are assembled so that when the substrate is aligned with any target only, sputtered material from that target reaches the substrate through the plasma column and from no other target. As the anode is rotated from the first target to align with the second target, during the transition the deposition takes place continuously, first from the first target, followed by deposition from both targets and finally from the second target, thereby controlling the interface structure and preventing any inter-layer contamination and providing a near perfect controlled interface.

15 Claims, 6 Drawing Figures

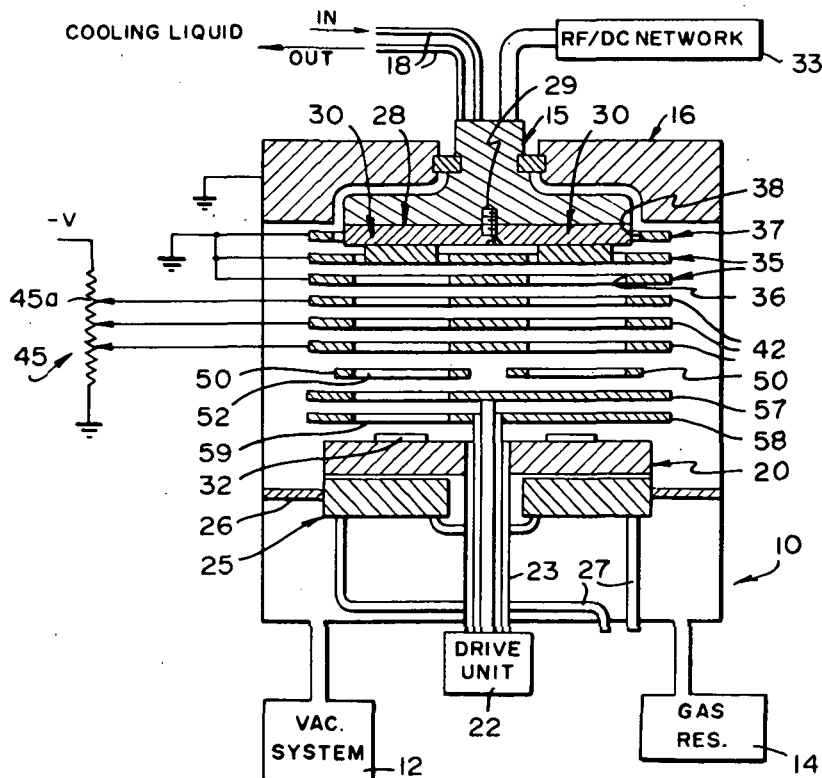


FIG. 1

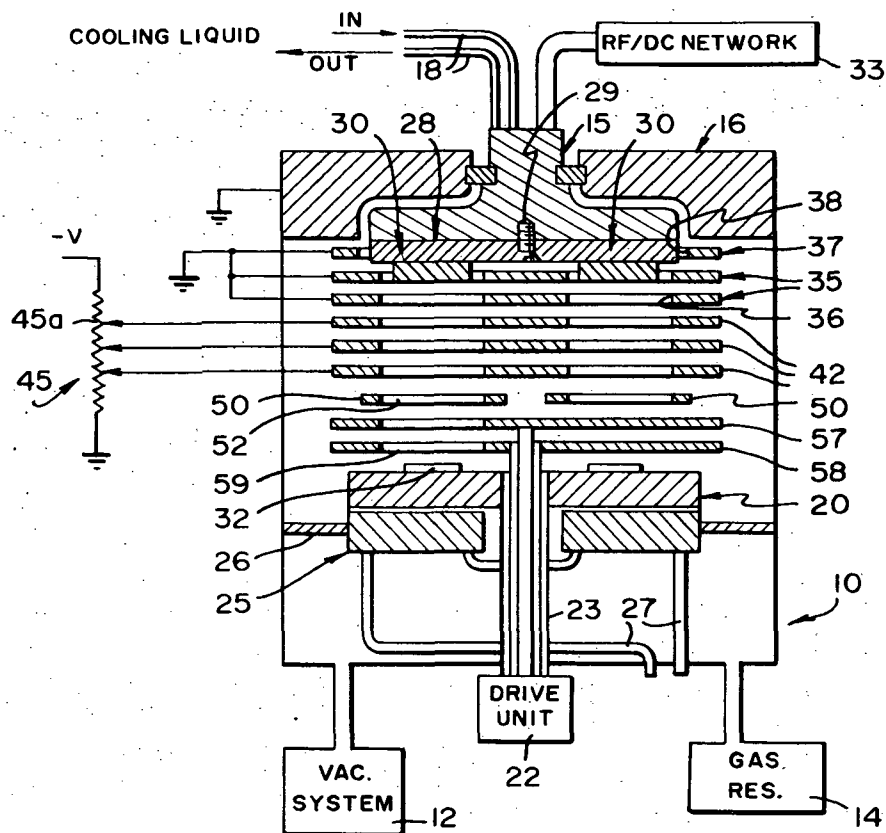


FIG. 2

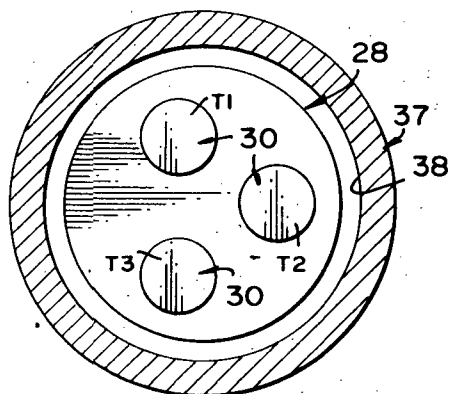


FIG. 3

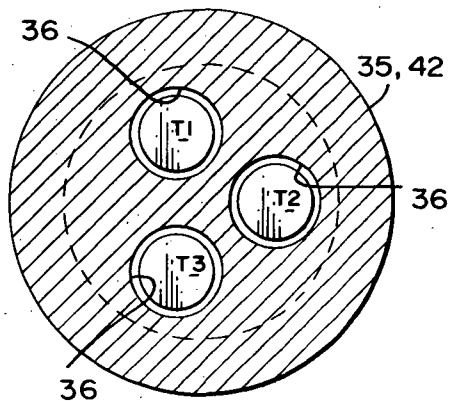


FIG. 4

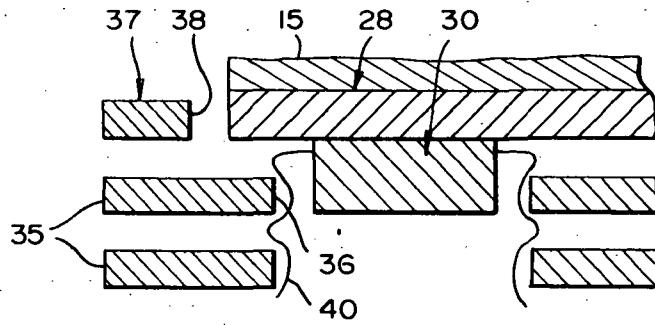


FIG. 5

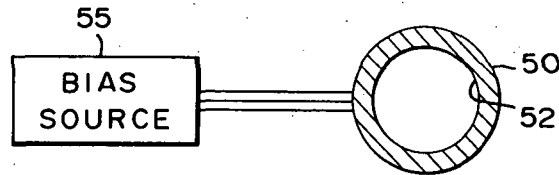
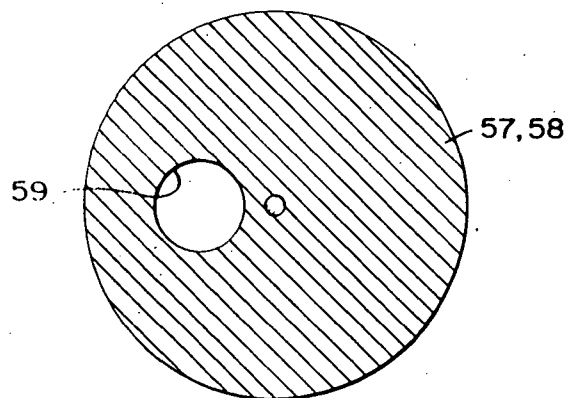


FIG. 6



MULTITARGET SEQUENTIAL SPUTTERING APPARATUS

ORIGIN OF INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to material deposition apparatus and, more particularly, to an apparatus for sequentially depositing layers of different materials with rigid control of the interface composition on a substrate by sputtering.

2. Description of the Prior Art

In sputter deposition, material is deposited as a result of ion bombardment of a target material or simply a target. The bombarding ions cause atoms of the target to be ejected therefrom at high velocity and become deposited on an appropriately exposed surface, usually referred to as a substrate. Typically, the target is physically and electrically connected to a cathode and the substrate is positioned on an anode. The ions are produced from a gas, generally inert or a gas mixture, present between the anode and cathode across which a DC or RF potential is applied.

In many applications, it is necessary to produce a multilayer structure of different materials in which each layer is of a very precise thickness and the interface between layers is absolutely free of contamination. This is particularly the case for electronic circuits or devices used in space exploration. Therein, the presence of any contamination between layers is not permissible due to the unknown effect of such contamination on the device's performance in space environments, or over long periods of operation.

Sputtering apparatus capable of depositing several layers of different materials on a single substrate are known. Generally, in such an apparatus or equipment, each target is supported on a separate cathode with its separate power network. After one layer is deposited from a first target, which is on one cathode, the power network of another cathode is activated. Then, after a period of target cleansing, which can be as long as several hours, the first layer is exposed to the cleansed target and a second layer is deposited from the second target. Unfortunately, in the interim period, i.e., between the time interval, the first layer was deposited and the start of the deposition of the second layer, the top surface of the first layer tends to become contaminated. Such contamination prevents perfect interface between deposited layers.

Manufacturers of multilayered units ignore the presence of the contamination between layers since for general commercial applications, its effect can be minimized by baking, i.e., annealing the multilayered structures. However, for applications in which the presence of any contamination cannot be permitted, the annealing is of no value. Thus, prior-art sputtering apparatus cannot be used. Also, in prior art sputtering equipment in which matter is depositable from different targets on a single substrate there is no capability to individually control the rate of deposition of the material of each target. As is known, materials used in sputter-

deposition have different rates of deposition, and therefore being able to individually control their sputtering rates is important. Also, heretofore in sputtering apparatus for sputtering different materials, several separate cathodes are employed, one per target, with each cathode having its own separate power network. This greatly increases the apparatus initial cost, and maintenance requirements.

OBJECTS AND SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide a new sputtering apparatus.

Another object of the present invention is to provide a new sputtering apparatus with which several layers of different materials can be sequentially deposited without contamination between layers.

Yet another object of the present invention is to provide a new sputtering apparatus with a single cathode, supporting a plurality of targets, and wherein the deposition rate from each target is individually controllable.

A further object of the present invention is to provide a new sputtering apparatus for successively depositing layers of different materials with continuous deposition and rigid control of the interface region between the layers.

These and other objects of the invention are achieved by providing a sputtering apparatus with a single cathode to which a plurality of targets of different materials are physically and electrically connected. An anode supports a substrate on which the plurality of layers of different materials is to be deposited. The anode is spaced apart from the cathode. A plurality of apertured plates which are spaced apart from one another are positioned near the cathode and towards the anode. These plates confine the plasma to extend in the form of a column from each target in the direction of the anode and to prevent its spreading as well as to prevent sputtered material cross contamination between the targets.

In addition, a plurality of spaced apart apertured biasing rings are positioned after the plates toward the anode. These biasing rings are charged with a potential gradient rising toward the anode potential in order to control, simultaneously, the cross section and therefore the plasma current in each column. Positioned in the path of each plasma column between the anode and the last biasing ring is a separate suppressor ring, which is connectable to a different biasing voltage. Its function is to control the individual current of each plasma and thereby individually control the rate of deposition from each target, independently of the rate of deposition from the other targets.

The plates, the biasing rings and the suppression rings are so positioned as to prevent any cross contamination between the targets. In addition, the apparatus includes movable shutters which are initially positioned so as to inhibit any material from any of the targets from reaching the substrate while the targets are being cleansed. Thereafter, the shutters are positioned to expose the substrate on the anode to a first target. After the desired layer thickness is deposited the shutters and the anode, supporting the substrate, are rotated so as to expose the latter to a second target from which matter is to be deposited. The targets are arranged so that as the substrate is moved from one position to the next during the transition period, matter is continuously deposited thereon, first from the first target, then from both tar-

gets when the substrate is at a midpoint between the two targets and finally only from the second target when the substrate is aligned therewith. The continuous deposition of matter on the substrate eliminates the possibility of contamination between deposited layers and insures perfect interface therebetween.

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side cross-sectional view of the basic embodiment of the invention;

FIGS. 2 and 3 are top views of different parts, shown in FIG. 1;

FIG. 4 is a partial side view useful in explaining one aspect of the invention; and

FIGS. 5 and 6 are additional top views of different parts, shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Attention is now directed to FIG. 1 wherein numeral 10 represents an air-tight chamber which is connected to a vacuum system 12, and to a reservoir 14 of metered gas, e.g., argon. As is known, the chamber is first evacuated to a low pressure, e.g., 1×10^{-7} Torr and is then backfilled with a small amount of gas from source 14 to an appropriate pressure on the order of several microns.

Supported in chamber 10 is a single cathode 15 which is shown suspended from a top plate 16. The cathode is cooled by a cooling liquid from an appropriate source (not shown) by means of interconnecting insulated conduits 18. Also supported in chamber 10 is an anode 20 which is rotatable by an external drive unit or motor 22, to which it is connected by shaft 23. A stationary liquid-cooled plate 25, with which the rotatable anode is in thermal contact, is fixedly positioned in the chamber, such as by means of brackets 26. Cooling liquid flows to and from plate 25 through conduits 27. The function of plate 25 is to remove heat from anode 20.

The arrangement described so far is similar to prior art sputtering apparatus. As shown in FIG. 1 an adapter plate 28 is attached to the cathode 15, such as by means of screw 29. Attached to the plate 28 are a plurality of targets 30. Since the plate 28 is at the cathode potential hereafter the targets will be thought of as being connected to and supported by the cathode 15. FIG. 2 is a top view of plate 28 and three targets 30, designated T1, T2 and T3. The plate 28 and the targets are shown as circular. As shown, the targets are not positioned symmetrically about the plate center. Rather, the angles between T1 and T2, between T2 and T3, and between T3 and T1, are 110° , 110° , and 140° , respectively, for reasons to be explained hereinafter. Each target is of a different material, a layer of which is to be deposited either directly on the anode 20 or on a substrate supported thereon. Such a substrate is shown in FIG. 1 and is designated by numeral 32.

As is the case in the prior art, a potential difference is established between the anode and cathode in the chamber. Typically, the anode is at ground potential and the cathode is at minus several Kv, e.g., approxi-

mately -3Kv . The large potential difference produces a glow discharge or plasma as a result of the ionization of the gas in the chamber. The ions strike the targets causing neutral atoms to become separated therefrom, generally referred to as sputtering, while the electrons travel to the positive anode. At least some of the neutral atoms reach the substrate on the anode to form the desired deposition layer. In the present invention, the anode is assumed to be at ground potential, and the negative potential is assumed to be applied to the cathode 15 from a network 33.

The targets must be cleansed before deposition can take place. Therefore, a shutter 57 has to be incorporated. It is placed near the anode and is at the anode potential, i.e., ground in the present example. The shutter has an opening which in the present invention is positioned so that when targets are cleansed the substrate is not exposed to the sputtered material from any of the targets.

In the present invention, since a single cathode is used when the potential difference is applied between the anode and the cathode during targets' cleansing and subsequent deposition, a plasma is formed for each target and matter is sputtered from each target. To insure the successive deposition of layers of the different target materials, in which each layer consists of only one target material, it is of primary importance to prevent any cross-contamination between the plasmas and the materials sputtered from the various targets. This can be achieved only by limiting the plasma from each target to be directed to the substrate as a separate column which is isolated from the other plasma columns, and by insuring that sputtered matter from any target reaches the substrate only when the latter is exposed to the particular plasma column.

As shown in FIG. 1, the apparatus includes a plurality of plates 35. Two such plates are shown. Each plate 35 includes 3 apertures 36 as shown in FIG. 3. Each aperture diameter is greater than the target diameter, by about 0.5 inch. The plates are fixedly positioned so that the centers of the apertures are aligned along vertical axes with the targets' centers. Thus, in a horizontal plane, the periphery of each aperture 36 is about $\frac{1}{4}$ inch from the projected edge of the target. The plates are spaced apart $\frac{1}{4}$ inch from one another, with the plate 35 closest to the targets being shown as about flush with targets' front faces.

Also included is a plate 37 with a single aperture 38 as shown in FIG. 2. Plate 37 surrounds the cathode plate 28. The diameter of aperture 38 is about $\frac{1}{2}$ inch greater than the plate diameter. The plate 37 is positioned so that it is about $\frac{1}{4}$ inch from the periphery of plate 28 and about $\frac{1}{4}$ inch from the top plate 35. The plates 35 and 37 are connected to ground potential. They perform two functions. The first is to prevent both plasma and sputtered matter cross contamination. The second function is to facilitate the plasma formation along each column.

As is known, plasma tends to flow along the longest path. As the plasma is formed near each target it tends to move outwardly toward the walls of chamber 10. The presence of the shields at ground potential confines the plasma to flow toward the anode. Due to the presence of the plates the plasma is shaped as a column with its outer surface being undulated as shown in FIG. 4 for a single target. The plasma is designated by numeral 40. It is thus seen that the shields restrict the

plasma within the desired column and prevent sputtered material cross-contamination between columns.

In addition to the plates, the apparatus of the present invention includes a plurality of biasing shields 42. Three such shields are shown in FIG. 1. Physically, the shields are identical to the plates 35. That is, each has three apertures 36, as shown in FIG. 3. The shields 42 are also spaced apart $\frac{1}{4}$ inch toward the anode. However, unlike plates 35 which are at ground potential, the shields 42 are connected to a divider network 45, represented as a resistor 45a connected between ground and a minus potential $-V$. The shield 42 closest to the anode is at a higher potential than the shields closest to lowest plate 35. Thus, all the shields 42 are at a lower potential than the anode which is at ground.

Due to the shields' potentials, the cross section of the plasma passing through each set of apertures of the shields is restricted thereby reducing plasma current which reduces the deposition rate. It should be pointed out that the biasing shields 42 simultaneously control the plasmas from all three targets in the three columns since the three plasmas flow through the same three biased shields. In addition to controlling the cross sections of all the three plasmas simultaneously, the shields 42, like plates 35 prevent cross contamination between the three columns. Shields 42 like plates 35 cause the shape of the plasma in each column to have the undulated outer surface as shown in FIG. 4 and thereby retain each plasma as a separate column and prevent plasma in one column from extending into an adjacent column.

In addition to the aforescribed parts the apparatus includes a separate biasing ring 50 for each column. A top view of one ring 50 is shown in FIG. 5. Its aperture 52 is of the same size as each aperture 36 of a shield 42. The three individual rings 50 are located in the same plane about $\frac{1}{4}$ inch below the lowest shield 42. Each ring 50 is connected to a separate bias source 55 (FIG. 5) of negative voltage. Such voltage, like the ones applied to shield 42 reduces plasma current and therefore the deposition rate. However, since herein, each column has a separately biasable ring 50, the plasma in each column is controllable independently of the plasmas in the other columns.

As further shown in FIG. 1 a pair of shutters 57 and 58 are included in chamber 10. Each is coupled by a separate shaft to motor 22. Each shutter has an aperture 59 (see FIG. 6) with a diameter which is generally equal to the diameter of the layer to be deposited. Shutter 57 is utilized as a barrier when the surfaces of the targets are cleansed, while shutter 58 is a target selector, used to select the particular target from which materials is deposited. Except during cleansing both shutters are moved together by motor 22.

The use of the apparatus will now be described in connection with a specific example in which it is assumed that a unit or structure consisting of layers from targets T1, T2 and T3 is to be produced. Either after or before placing the substrate 32 on the anode and before establishing the necessary gas pressure in chamber 10, shutter 58 is rotated so that its aperture is aligned with the column of T1 and shutter 57 is rotated so that its aperture is in the 140° zone (see FIG. 2) between T3 and T1. Then the potentials are applied to the cathode and anode. As a result, target sputtering takes place thereby cleansing all three targets. The potential is applied continuously throughout the entire operation.

The potential to network 33 may be applied at any point before deposition begins. As the targets are cleansed due to the position of shutter 57 none of the sputtered material reaches the substrate 32.

After the targets are cleansed, the shutter 57 is rotated to align its aperture with the column of T1. Thus, the substrate 32 is exposed to target T1 and therefore the first layer is deposited thereon. The bias on ring 50 in this column may be controlled to control the deposition rate from T1. After the layer from T1 reaches the desired thickness both shutters 57 and 58 are rotated together (clockwise in FIG. 2) with the anode 20 toward the column of T2.

As the anode and the shutters move from the position in which the substrate 32 and the shutters' apertures are aligned in the column of T1 to that of T2, a deposition transition takes place. The spacing between columns in the chamber and the movement of the anode shutters are such that during the entire transition some material is always deposited on the substrate. As the substrate and the shutters move away from the column of T1, less material from T1 is deposited on the substrate until the substrate is completely blocked off from the T1 column and is aligned in the T2 column. Then only material from T2 is deposited to form the second layer. In operation, when the substrate and the apertures of shutters 57 and 58 are midpoint between the T1 and T2 columns, i.e., about 55° (see FIG. 2) from either column some matter from each of targets T1 and T2 gets deposited on the substrate. However, as the substrate becomes aligned with the T2 column, only matter from T2 is deposited thereon. Any matter from either T1 or T3 is blocked off by the plates, shield rings as well as by the shutters which are between the targets and the substrate.

The continuous deposition during the transition from T1 to T2 eliminates the presence of any contaminant between the deposited layers. Also, it insures perfect interface between the two deposited layers of materials from T1 and T2. After reaching the T2 column, the shutters remain thereat until the layer of T2 material reaches the desired thickness. Then the anode and the shutters are moved to column T3 to deposit the T3 material. Again, during the transition from T2 to T3 material is continuously deposited on the substrate to eliminate contamination between the second and third layers and provide nearly perfect interface therebetween.

The apparatus of the present invention was used to deposit layers of molybdenum and gold on nickel foil with perfect adhesion. It was also used to deposit in sequence layers of titanium, molybdenum and gold on an aluminum oxide substrate. When etched the layers which were on the order of 500 to 1,000A (angstrom) in thickness were found to be without fault. That is, the interfaces between layers were perfect and did not contain any contaminants. It should be appreciated that the invention is not intended to be limited for use with the above-mentioned materials. Any sputterable materials may be used therein. Also, more than one substrate may be simultaneously exposed in the same column.

From the foregoing, it should thus be apparent that in the apparatus of the present invention, once deposition starts from one target it continues until completed to produce a multilayered unit or structure without interruption. Thus, interlayer contamination is prevented. The plates 35 and 37 and the shields 42 are

spaced to confine the plasma in each column and avoid sputtered material cross contamination in adjacent columns. The spacing between adjacent plates and shields generally in the order of $\frac{1}{4}$ inch, contains the plasma in each column, the plasma being characterized by the undulated outer surface. By providing the bias network 45, the currents in all three plasmas are controlled simultaneously. By providing a separate biasing ring for each column, deposition rate from each target is separately controllable. By providing a single cathode which supports several targets, only a single power network 33 is required.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and art and may readily occur to those skilled in the art consequently, it is intended that the claims be interpreted to cover such modifications and equivalents.

What is claimed is:

1. A sputtering apparatus comprising:
 - a chamber for containing an inert gas at a selected pressure;
 - a single stationary cathode in said chamber said cathode having means to support a plurality of different target materials connected thereto;
 - a rotatable anode in said chamber spaced apart from said cathode along a chamber axis and having selected area means for supporting a plurality of substrates;
 - a plurality of spaced apart elements supported between said anode and said cathode, each element defining a plurality of apertures, whereby each of said targets is exposable through a different set of apertures of said plates to a selected area of said anode aligned with the target-material along a different axis parallel to said chamber axis;
 - power means for applying a potential difference across said anode and cathode to ionize said gas to form plasma containing gas ions and electrons, said ions striking said targets to dislodge neutral material particles therefrom, at least some of which are directed to said anode;
 - potential means for controlling the potentials of said elements so as to control the ionization current of each plasma between each target and directed to said anode through a different set of apertures of said elements, said plates and apertures being spaced between said anode and cathode whereby when the selected area of said anode is aligned with a first of said targets only neutral material particles from said first target reach said selected area, with neutral material particles from either or both said first and second elements reaching said selected anode area continuously as said anode is rotated and the selected anode area is moved from alignment with said first target to alignment with said second target.
2. The apparatus as described in claim 1 further including rotatable apertured shutter means adjacent said anode positionable in a first position to inhibit the neutral material particles from any of said targets from reaching said selected anode area and positionable in any one of other positions so as to expose said selected anode area to the neutral material particles of at least one of said targets.
3. The apparatus as described in claim 2 wherein said plurality of elements includes a second group of aper-

tured elements spaced apart between the element of said first group most remote from said cathode toward said anode, with said potential means applying a different potential to each of said second group of elements.

4. The apparatus as described in claim 3 further including a separate biasable ring in the path of each plasma extending from a different target and means for controlling the ring potential to control the plasma ionization current and thereby separately control the rate of sputtering of each target.

5. The apparatus as described in claim 4 wherein the element of said second group closest to said anode is at the anode potential and each succeeding element of said second group positioned toward said cathode is at a decreasing potential with respect to the anode potential.

6. The apparatus as described in claim 1 wherein said plurality of elements includes a first group of elements adjacent to said cathode and spaced toward said anode, and connected to said potential means to the anode potential so as to confine the plasma from each target to extend toward the anode through a different set of apertures of said elements.

7. The apparatus as described in claim 6 wherein said plurality of elements includes a second group of apertured elements spaced apart between the element of said first group most remote from said cathode toward said anode, with said potential means applying a different potential to each of said second group of elements.

8. The apparatus as described in claim 7 wherein the element of said second group closest to said anode is at the anode potential and each succeeding element of said second group positioned toward said cathode is at a decreasing potential with respect to the anode potential.

9. The apparatus as described in claim 6 further including a separate biasable ring in the path of each plasma extending from a different target and means for controlling the ring potential to control the plasma ionization current and thereby separately control the rate of sputtering of each target.

10. A sputtering apparatus for use in depositing on a substrate a plurality of layers of different materials, with the interface between adjacent layers consisting of only materials of the two adjacent layers comprising:

- a chamber for containing an inert gas at a selected low pressure;
- a single stationary cathode in said chamber, said cathode having means for supporting at least first and second target materials each having an exposed surface and defining a center;
- a rotatable anode in said chamber spaced apart from said cathode along a chamber axis for supporting a substrate thereon;
- a plurality of elements spaced apart from one another and disposed between said anode and cathode, each element defining first and second apertures, the first apertures of said elements defining a periphery of a first column extending from said first target to said anode along a first axis parallel to said chamber axis, and the second apertures defining the periphery of a second column extending from said second target to said anode along a second axis parallel to said chamber axis;

power means connected to said cathode and anode for applying a potential difference therebetween whereby said gas ionizes to form a first plasma in

said first column extending from said first target to said anode and a second plasma in said second column extending from said second target to said anode, said first and second plasmas including ions which respectively sputter said first and second targets to cause neutral particles of said targets to be separated therefrom, at least some of the particles of the first and second targets travel through said first and second columns respectively toward said anode;

potential means coupled to said elements for controlling the plasma to be substantially confined to its respective column and for controlling the plasma ionization current; and

control means for rotating said anode to a first position to sequentially align said substrate with said first column and thereafter with said second column, the apertures of said elements being positioned whereby when said substrate aligned alonged in said first column only particles from said first target reach said substrate and are deposited thereon to form a first target material layer and when said substrate is aligned in said second column with said target only particles from said second target reach said substrate and are deposited thereon as a second target material layer and as said substrate is moved from alignment with said first column to alignment with second column particles from at least one of the targets continuously reaches said substrate to be deposited thereon.

11. The apparatus as described in claim 10 further including a rotatable shutter adapted to shield said substrate from particles from any of said targets, said shutter being rotatable with said anode to expose said substrate to either of said targets.

12. The apparatus as described in claim 11 further including a separate biasing ring associated with each column to control the ionization current of each plasma independently of the ionization current in the other column, thereby independently controlling the sputtering rate of each of said targets.

13. The apparatus as described in claim 12 wherein said potential means are capable of controlling the potential of a first group of said elements positioned adjacent to said cathode to be at said anode potential to thereby prevent plasma spreading out of its respective column.

14. The apparatus as described in claim 13 wherein said potential means are capable of variably controlling the potentials of a second group of said elements, positioned between said first group and said anode with the element of said second group closest to said anode being at the anode potential.

15. The apparatus as described in claim 11 wherein said potential means are capable of controlling the potential of a first group of said elements positioned adjacent to said cathode to be at said anode potential to thereby prevent plasma spreading out of its respective column.

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